Improved Techniques for Targeting Additional Observations to Improve Forecast Skill

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LONG-TERM GOAL

This project aims to improve weather forecasts using adaptive observation techniques based on targeted singular vector analysis with a particular focus on severe weather events in the tropics and extratropics in the range 0–5 days.

OBJECTIVES

The first objective is to assess the extent to which ensemble forecasts of severe weather events in which initial error is represented either by singular vectors or analyses differences can be relied on to include a member which is close to reality (in the range 0–5 days). A second objective is to investigate the effectiveness of targeted observing networks in the sensitive regions of the atmosphere defined by singular vectors. The sensitivity of the improvement in forecast skill to the horizontal and vertical extent as well as the density of additional observations will be studied. It will be assessed whether the assimilation system can be geared to more readily accept adaptive observations made in currently data sparse regions. A third objective will be to study what impact the formulation of the linearized diabatic terms in the tangent model and the choice of analysis error covariance norm at initial time have on the structure of the singular vectors. A fourth objective is to study how to best define the sensitive regions of the atmosphere based on a given set of singular vectors. Finally, it is hoped to be able to use the improved targeting techniques in real-time targeted observation experiments.

APPROACH

Numerical experiments are performed in which a simulated atmosphere is used as a surrogate 'true' state in order to investigate the impact from different strategies to distribute additional observations. The impact is evaluated by comparing the skill of the forecasts that use additional observations with the skill of the control forecast that does not use the additional observations. The forecast skill is measured with respect to the simulated truth. The same model is used for the forecasts and for the prediction of the true atmospheric evolution. Thus, the forecast model is perfect within these idealized experiments. The forecast error is entirely due to the analysis error. The methodology is similar to that used by Bergot et al. (1999).

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Three methods of representing the analysis error of the control are considered. In the first and second method the analysis error is composed of singular vectors. The singular vectors are optimized for growth of total energy in the first method (total energy singular vectors, TESVs). In the second method, Hessian singular vectors (HSVs) are used. They are computed with an initial time norm that is based on an estimate of the analysis error covariance metric. An estimate of the analysis error covariance is calculated from the Hessian of the 4DVAR cost function. In the third method, the control and the true initial conditions are chosen from a set of 4 analyses coming from different forecast centres. An analysis that results in a poor forecast is chosen as control and the analysis that results in the best forecast is chosen as truth.

A set of simultaneous observations of wind and temperature are constructed from the truth trajectory. These *synthetic* observations are vertical soundings from the surface to 200 hPa. No observational error is added to the data. However, the synthetic observations are assimilated assuming an observation error estimate which is used operationally for radiosondes. The synthetic observations are assimilated with a 4DVAR scheme. The observation time is at the centre of the 6-hour assimilation period. The initial condition of the control trajectory is used as first guess.

All strategies tested here aim to increase the number of accurate observations in regions of the atmosphere that lack accurate observations. These regions will be referred to as data-sparse. Targeting strategies focus all additional observational resources in the most dynamically sensitive region(s), that is, the regions where they are likely to improve the forecast in the verification region the most. Alternatively, additional observations can be distributed over a larger part of the data-sparse region. Here, the observations are distributed in a random manner in the data-sparse region by selecting sounding locations from a set covering the data-sparse region homogeneously.

The singular vector based targeting assumes that the dynamically sensitive regions can be identified as those regions where the amplitude of the leading singular vectors is large. The targeted sounding locations are chosen from a set of locations that cover the data-sparse region at a given horizontal resolution. A weighted average F of the vertically integrated energy of the leading singular vectors is used to rank the sounding locations according to their potential contribution to a forecast improvement. The target is defined as the subset of N locations at which the value of F is larger than at any of the other locations, where N is the number of soundings that shall be distributed.

The singular vectors used for F are targeted; they are the structures having maximum total energy in the verification region at final time. The choice of the norm at initial time is investigated. Targets are computed with total energy singular vectors (TESV-targets) and with Hessian singular vectors (HSV-targets). Furthermore, it is examined how the target depends on the definition of F, i.e. the weights, the form of energy (kinetic, potential or total) and the layer over which the energy is integrated.

Furthermore, the region in which additional data improve the forecast the most is identified with a ”brute force and ignorance” approach, which is independent of singular vectors. The location of this most sensitive region is compared with the singular vector targets.

Tim Palmer is managing the overall development of the ECMWF ensemble prediction system. Martin Leutbecher is investigating the effect of synthetic observations on the analyses and subsequent forecasts. Jan Barkmeijer is studying how the singular vector structure depends on the choice of the initial time norm and the inclusion of moist processes. Kamal Puri is examining tropical cyclone evolution with the ECMWF ensemble prediction system. At Meteo-France, Thierry Bergot is assessing the targeted data collected in the FASTEX experiment, Gwenaëlle Hello and Alex Doerenbecher are working on the relationships between targeting and data assimilation and Nadia Fourrie studies how targeting ideas may influence the use of TOVS data.

WORK COMPLETED

The impact of additional observations — targeted and untargeted — has been studied for the first French storm, which occured in December 1999. All three methods of representing initial error have been tested.

The impact of additional observations for improving the track forecast of tropical Cyclone Zeb has been studied. In this case initial error is represented by targeted diabatic total energy singular vectors. (Results are not discussed here.)

RESULTS

Results obtained for the 48 hour forecast of the first French storm are summarized here.

The impact of observations distributed in the complement of singular vector targets is very small when initial error is represented by singular vectors. This small impact is not only due to the smaller growth of error in the complement of the singular vector target. In addition, initial error composed of singular vectors is quite small in large parts of the complement of the singular vector target. Additional observations located in regions of small initial error do not change the analysis much. Therefore, the impact of additional observations distributed randomly over a larger part of the data-sparse region may be unrealistically small.

In the remainder of this section the evaluation of observing network supplements is based on experiments in which initial error is represented by analysis differences. The control and the truth are chosen to be the forecast from the ECMWF analysis and the forecast from the Meteo France analysis, respectively. The initial error given by the difference of the two analyses is independent of singular vectors and is considered to be a more realistic estimate of the analysis error. Thus, the evaluation is more credible than the evaluation using singular vector initial error. The focus of the study is on the best distribution of 40 additional soundings. The SV-targets and the random distributions are chosen from sets of locations that cover the data sparse region with a constant number of soundings per area. This is achieved by decreasing the longitudinal resolution towards the pole. The SV-targets are constructed from a set of locations with 2.5° latitudinal resolution. This corresponds to a spatial resolution of 280 km in the meridional and zonal direction.

The average forecast improvement due to additional soundings distributed randomly in the data-sparse region depends on the sampling method. The impact has been evaluated for random distributions of sounding locations chosen from three different sets of locations: a set of 219 locations covering the Atlantic and Polar region at a latitudinal resolution of 5° (AP5), a set of 218 locations covering the West-Atlantic region at a latitudinal resolution of 2.5° (WA2.5, shown in Fig. 1a) a set of 58 locations covering the West-Atlantic region at a latitudinal resolution of 5° (WA5). An average impact over a sample of 5 experiments is computed for each set AP5, WA5,

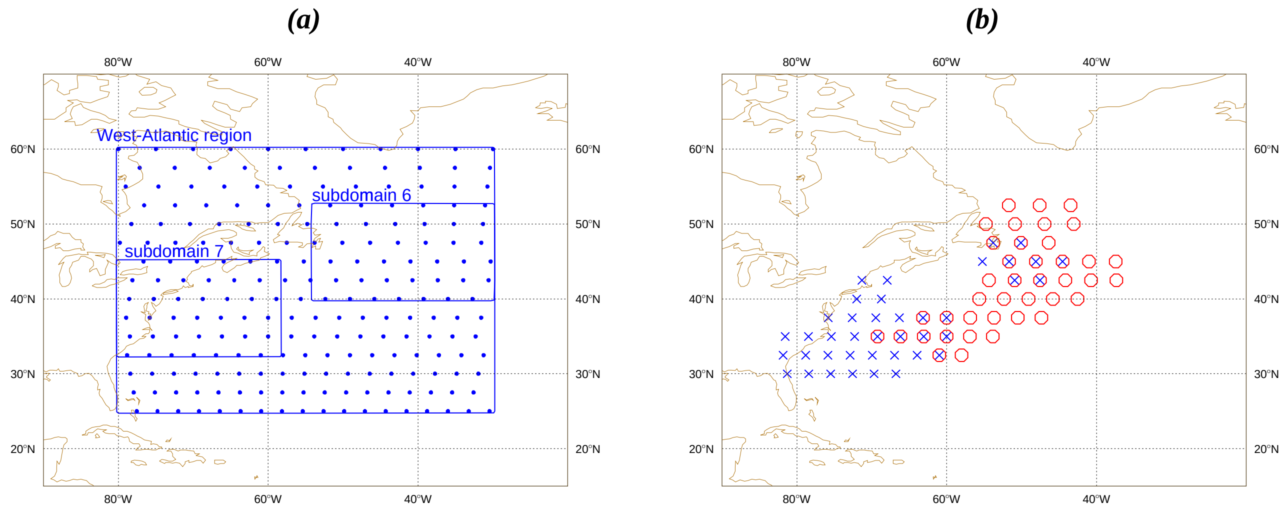

Fig. 1: (a) West-Atlantic region with 218 sounding locations (•) and subdomains 6 and 7 containing 40 locations each. (b) Singular vector targets computed from the vertically integrated total energy of the leading 5 total energy singular vectors (×) and from the leading 5 Hessian singular vectors (○).

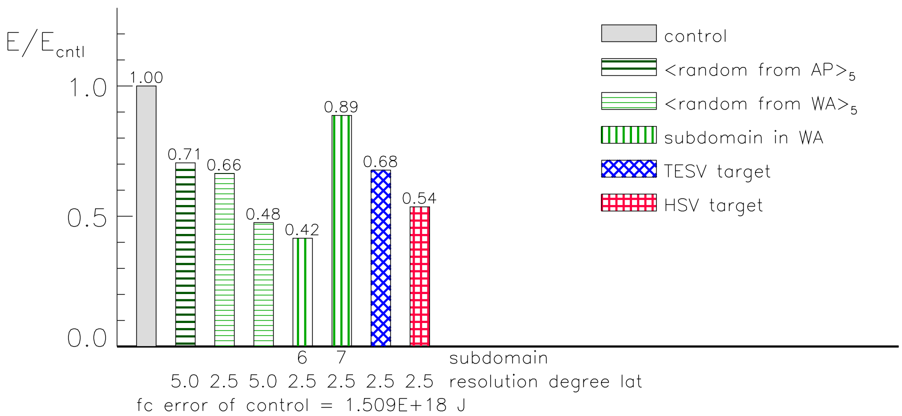

Fig. 2: Total energy of forecast error of control and experiments using 40 synthetic soundings. The error computed with respect to the simulated truth is integrated from the surface to 500 hPa in the verification region 20°W–20°E, 35°–60°N. The forecast error is averaged over 5 experiments for the random distributions in AP5, WA2.5, WA5. Forecast lead time: 48 hour, valid time: 1999 Dec 26, 12 UT.

WA2.5, as the impact varies considerably between different random distributions chosen from the same set. Figure 2 shows the average total energy of the 48-hour forecast error in the verification region. The forecast error is quite similar for random distributions chosen from AP5 and random distributions chosen from WA2.5. The forecast error for random distributions chosen from WA5 is considerably smaller.

Targets computed with the vertically integrated total energy of the five leading singular vectors are shown in Fig. 1b. The singular values are chosen as weights in the ranking function. The HSV-target describes a connected region. The TESV-target is split into two regions. The large region contains 32 soundings, the small region 8 soundings. Each region has 7 soundings in common with the HSV-target. The impact from the TESV-target is similar to the average impact of random distributions in AP5 and WA2.5 in terms of the total energy of the 48-hour forecast error (Fig. 2).

(a) analysis ***(b) truth*** ***(c) control*** ***(d) HSV-target***

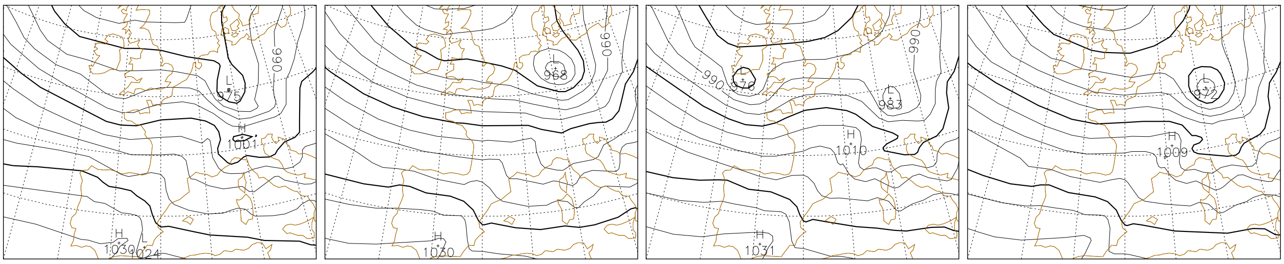

Fig. 3: Sea level pressure at 1999 Dec 26, 12 UT. (a) ECMWF-analysis, (b,c) 48-hour forecasts from the Météo-France and ECMWF analysis, respectively, (d) 48-hour forecast using the 40 soundings of the HSV-target. The sounding locations are shown in Fig. 1b.

The forecast is more improved by using the observations belonging to the HSV-target. However, on average the forecast is improved even more by random distributions in WA5. Sea level pressure maps are shown in Fig. 3. The low over Germany, the “first French storm” is too shallow in the control. In addition, there is a storm south of Ireland in the control that did not occur. The use of soundings from the HSV-target removes the latter storm and lowers the central pressure of the first French storm from 983 hPa (control) to 972 hPa. With the soundings from the TESV-target the central pressure of the first French storm is reduced to 977 hPa and the system south of Ireland is not entirely removed.

In the “brute force and ignorance” approach the region in which additional observations improve the forecast the most is searched explicitly. To keep the task computationally tractable, the search is restricted to finding the best position of a rectangular array of soundings in the West-Atlantic. To this extent the West-Atlantic region is divided into 14 overlapping subdomains containing 40 soundings each (Fig. 1a). The subdomains have an extension of 1800 km and 1400 km in the zonal and meridional direction, respectively. Adjacent arrays have about half of the soundings in common. Any other subdomain in the West-Atlantic region with the same extensions would share more than half of the sounding locations with one of the 14 subdomains. The subdomain leading to the best forecast is subdomain 6 (Fig. 2). It is more similar to the HSV-target (23 soundings in common) than to the TESV-target (7 soundings in common). The forecast error obtained with each of the other subdomains is larger than the forecast error obtained with the HSV-target. Four subdomains result in a lower forecast error than the TESV-target.

Alternative singular vector targets can be computed that are more similar to subdomain 6 by changing the ranking function F. However, the better agreement of subdomain 6 with HSV-targets than with TESV-targets does not change if F is altered. The best choice for F yields a HSV-target that has 35 soundings in common with subdomain 6.

IMPACT/APPLICATIONS

This study may help transform the method by which atmospheric observations are taken. At the moment, the project rather confirms the overall singular vector approach of targeting as implemented during FASTEX by several centers including the NRL, although the choice of an analysis error covariance-based norm appears important.

RELATED PROJECTS

The techniques described in this report could be utilised in the proposed THORPEX experiment.

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